

EFW High Rate Justification

Summary

We have calculated the total duration of different intervals of intense electric fields associated with intervals of substorm injections, transits through regions of overlap between the ring current plasma and plasmasphere, turbulent small scale wave fields associated imbedded in ULF waves. We also support burst sampling of less intense waves existing over large portions of the inner magnetosphere where they are important candidates for efficiently scattering and accelerating energetic particles. This latter class of waves motivates bursts recordings of E, B, and density data at 0.5 Re intervals over the entire orbit of the spacecraft. The total duration of all these intervals (discussed in the last Table of this document) was about 6040 seconds per orbit during major storms and energetic electron acceleration events. With the AO TM we could sample only about 1000 seconds of data. There was a strong risk of missing or not being able to diagnose the most important acceleration structures and how they accelerate particles. In the High Rate TM, we now record ~ 6168 seconds of this burst waveform data. The formats and quantities are described in detail in the accompanying EFW telemetry format file.

The enhanced high rate telemetry supports primarily four kinds of data:

- 1) Burst measurements of 3 -D vector electric field and magnetic fields and density fluctuations (obtained from spacecraft potential) over the frequency range from dc-100 Hz
- 2) Burst recordings which provide interferometric measurements of phase velocity and k vector (scale sizes and direction of propagation) in the spin plane of the spacecraft. These measurements are obtained by timing between individual electric field sensors. Two different rates of interferometric measurements are supported. A medium resolution burst rate allowing phase velocities up to 300 km/s to be determined. A higher rate that allows 1000 km/s phase velocities to be determined. We telemeter brief snapshots of interferometric data imbedded within the longer wave form data. The cumulative duration of these brief snapshots is 360s. This data is important for mode identification and also to understand which waves interact most efficiently (resonantly) with the different parts of phase space.
- 3) It also supports an increased telemetry rate for the measurement of spacecraft potential which provides an estimate of cold plasmaspheric density. The continuous rate TM provides a measure of the cold plasma fluctuations from dc to 12 Hz. Burst rate telemetry includes this density determination from dc to 100 Hz. The rationale for these measurements is that it 1) provides an important parameter for distinguishing between different modes, and 2) allows us to assess the small scale density structure of the plasma. Waves must propagate through this medium and the small scale structures refract and reflect waves and help determine their coherence length. The coherence length is a major determiner of how long waves can interact with electrons and how efficiently they can accelerate them.
- 4) During high rate periods, we transmit continuous mode data containing spectra cross correlation and phase lag analysis every six seconds. This will provide continuous information on the k vector in the spin plane and the phase velocity in the spin plane.

The following tables delineate the A) goals supporting the above measurements. A separate file presents the survey and high rate data transmitted, shows the changes in TM, and maps them to the justifying goals presented below.

AO Goal 1 Differentiate between processes affecting acceleration and transport of radiation belt particles.

Sub-Objective	Methodology	Electric Field Wave Measurements
<p><u>Objective 1.1a</u> Determine the effects of local acceleration processes: the amount of energization, the spatial regions, and temporal variability.</p>	<p>Measure the wave fields and particle distributions in situ and look for the effect of the waves on the particle energy spectra and on particle pitch angle distributions. Assess the contributions of different wave modes in causing modifications to the particle distributions. The effect of waves on particle distributions must be measured at various local times where different wave fields are present. Subsequent measurements must be made with time separations ranging from minutes to hours to determine the rates of energy and pitch angle diffusion. Pitch angle distributions must be measured at the same local times to obviate the effects of drift shell splitting.</p>	<p>Measure 3d electric and magnetic wave forms and power spectra from 1 Hz to 10 KHz; . Amplitude: +/- 400 mV/m over dc-100 Hz ; Amplitude: +/-10mV/m over chorus range 1-10 khz</p> <p>Measure entire wave spectra and wave form without saturating due to large amplitude waves at low frequencies.</p> <p>100% Spectral coverage over entire orbit every spin period. Cadence ~6 seconds (1/2 spin). Need power spectra, coherence spectra, phase lag spectra (between opposite probes).Power spectra over 1 Hz to 10 kHz with sensitivity of TBD V^2/mHz and TBD nT^2/Hz and dynamic range of 100 dB</p> <p>Need burst wave form coverage of about 30 minutes out of each orbit during major storms and major electron acceleration intervals to measure representative waveforms during the 10 minute intervals associated with each of 4-5 injection events and 2 current sheet/ spatial boundaries. Need approximately 50% coverage of these intense ~10 minute acceleration intervals(5% coverage orbit averaged)</p> <p>Also need representative E and B waveform bursts (at ~ 1 Re) intervals over 2 Re to 5.8 Re) over all MLT. Each burst lasts ~ 1 minute to assess impact of spatially extensive low amplitude waves deep in the inner magnetospheres on electron acceleration.</p>
	<p>Measure the characteristics (k, amplitude, spectrum, etc) of the wave fields that produce the most radiation belt acceleration in order to determine the radial, energy and pitch angle diffusion coefficients. Compare calculations of radial, energy, and pitch angle diffusion on the particle distribution functions. Need to be able distinguish between coherent and diffusive acceleration using burst wave form information. Measure wave properties at times of strongest particle acceleration over the entire orbit and all magnetic local time sectors. Determine spatial scales of accelerating structures/wave fields by using two spacecraft.</p>	<p>Interferometric modes: representative bursts sampling of 6 probe-spacecraft potentials at ~2kHz to 10 kHz sampling rates to determine k , phase velocities of of strongly electrostatic waves. Interferometric bursts coincide with waveform bursts but last about one tenth as long. Measure scale sizes from .1-20 km (range of gyroradii of thermal electron (1-100eV) in radiation belts). Determine direction of scale size propagation for waves relative to magnetic field for velocities of 1 km/s to 500 km/s.</p> <p>Need Spectra al measurements from two spacecraft separated by 2000 km to 20000 km in azimuthal and radial distances to access spatial extent of wave fields.</p> <p>Goal: measure small scale density fluctuations that determine the propagation path coherence of the waves of the waves and how long they interact with an energetic particle: Cold electron density form dc-12 Hz 0-100cm⁻³</p>
<p><u>Goal 1.1e</u> Investigate whether other local acceleration or transport processes (such as Alfvén waves, electrostatic structures, lower hybrid waves etc.) have important effects on radiation belt structure and dynamics or on the specific characteristics of individual events.</p>	<p>Determine the amplitude, k-vectors, and phase velocity, and coherence length of the waves in order to determine their ability to accelerate different portions of the energetic electron phase space. Measure these properties during episodes and locations of especially strong turbulence (ie at injection events, region of overlap between freshly injected electrons and ions and the plasmasphere, current layers, shocks etc.). Also survey turbulence at different radial and MLT positions between apogee and ~ 2 Re geocentric distance.</p>	

AO Goal 2 Differentiate among competing mechanisms affecting precipitation and loss in the outer radiation belt.		
Sub-Objective	Methodology	Measurements
<p><u>AO Objective 2a</u> Quantify loss rates vs. energy and location for wave induced pitch-angle scattering mechanisms and their variability</p>	<p>Measure the detailed properties of waves in terms of frequency, intensity, propagation direction, and temporal evolution throughout the radiation belts simultaneously at two points. Assess their ability to scatter energetic electrons. Provide these measurements in the spatial regions (ie over lap between hot ring current plasma and plasmasphere, during intervals of injection fronts, on regions of strong current sheets and convection boundaries and at the radial and MLT positions of hiss, chorus, and EMIC waves and in the slot region.</p>	<p>See measurements for Goal 1. We need to assess the same waves and their properties with the same duty cycle during the same intervals of accelerations and locations.</p>

Goal 3 "New Belts"		
Sub-Goal	Methodology	Measurement
3 c) Determine the relative roles of non-adiabatic and adiabatic processes in energizing the new populations	Use in-situ measurement of particle fluxes with high resolution in energy and pitch-angle distributions and concurrent wave data from dual RBSP and other ancillary data to determine the average loss rate at different L and compare quantitatively to ground based and other observations.	Survey wave properties from 1 Hz (old 10 Hz) to 10 kHz including spectrum, polarization, propagation properties. Additionally provide occasional high temporal resolution for bursty emissions such as chorus.
3e) Determine electron and ion loss rates vs. energy for each relevant mechanism for the new belt	Use multipoint measurements from the two RBSP spacecraft plus GOES and other ancillary data to characterize the time evolution, direction of propagation and local time dependence of various VLF waves and EMIC waves as well as the particle flux and pitch angle evolution. Use these measurements to calculate the loss rates of particles of different energies due to precipitation into the atmosphere which occurs regardless of where new belts are formed. Determine actual loss rates for electrons using available concurrent observations on other spacecraft/ground.	Survey wave properties from 1.0 Hz (old 10 Hz) to 10 kHz including spectrum, polarization, propagation properties. Additionally provide occasional high temporal resolution for bursty emissions such as chorus.

AO Goal 4 Quantify relative contribution of adiabatic and non-adiabatic processes to energization of radiation belt particles		
Sub-Objective	Methodology	Measurements
.AO Goal 4.1) Measure and model the interactions that violate the first adiabatic invariant that cause pitch-angle scattering stochastic energy diffusion, radial diffusion (possible interactions include: whistler mode interactions, EMIC, small scale Alfvén waves, lower hybrid waves and other small scale waves and structures).	Use simultaneously measured electric and magnetic fields from the two spacecraft to evaluate the properties of the waves and structures, which are likely to be in gyro-resonance with different particle populations, before, during and after the acceleration interval. Measure detailed properties necessary to determine mode structure including wave normal directions, phase velocity, spatial scales perpendicular and parallel to B, E/B ratios, locations of regions of intense wave fields in the inner magnetosphere.	Measure 3-D electric and magnetic fields from 0.5 Hz to 12 kHz. Measure E-field amplitudes +/- 400 mV/m with sensitivity of 0.1 mV/m Measure B-field amplitudes from +/- 10 nT to 1pT. Measure spectra and also burst wave forms. Determine direction of propagation and phase velocity, coherence for both electrostatic and electromagnetic waves. Range of phase velocities for electrostatic waves is +/- 1000 km/s. For whistler waves phase velocities up to 30,000 km/s
AO Goal 4.2 Measure and model the interactions that violate the second adiabatic invariant (includes processes that vary the distances between mirror point and also those involving bounce resonance, and/or parallel electric field acceleration	Method 4.2c. Evaluate the waves and plasma structures that accelerate particles in the parallel direction. Measurements of electric and magnetic fields should be used to provide information on the relevant wave modes, their coherence, scales and phase velocities, and their ability to energize electrons and ions at various energies. The distributions functions and the properties of plasma structures destabilizing these waves should be measured simultaneously so that the circumstances under which these processes are likely to occur can be understood.	Measurement: 3-D Electric fields from 1 Hz to 100 Hz over range 1-500 mV/m. associated with small scale structures and waves that can produce significant parallel potential drops which are resonant with over energetic electron or ion bounce periods. Use interferometric timing to determine perpendicular scale sizes over 0.1 to 20 km. Use realistic dispersion relations to determine spatial scales from 5 km to 1000 km and parallel "potential drops". Evaluate the effect of numerous bounces through these structures. Evaluate the coherence, spatial durations and spatial extent of the wave fields responsible for this mode of acceleration. Use spacecraft potential to determine background density which along with magnetic fields is an important determinant of wave velocity
AO Objective 4.5 Understand and quantify the interplay between these mechanisms as they occur during the same acceleration processes	M4.5b. Determine the ability of the large scale structures to provide the free energy sources which drive small scale structures and wave fields. Measure the free energy sources generated by the large-scale structures in the form of unstable distributions	Use all of above. Provide measurements of small scale structures/waves in concert with large scale electric field, injection event electric fields and distribution functions of unstable ion and electrons.

AO Goal 5 Understand the role of seed or source electrons for relativistic particle events		
Sub-Objective	Methodology	Measurements
AO Goal 5.c. Determine how source populations are transported to the radiation belts and energized	Measure 2-point DC and wave fields in source through to acceleration regions in order to quantify the underlying electric fields active during the source populations' transport and time evolution.	DC electric fields from +/- 400 mV/m with accuracy of 0.5 mV/m or 10% of field magnitude (which ever is larger) from dc to 10 Hz on two spacecraft. Need E and B wave measurements as described in Goal 1. Need these measurements during simultaneous measurement of source population distribution functions and phase spacedistributions at TBD rates.
AO Goal 5.e. Understand how the unstable plasma distributions generate waves that interact with radiation belt and ring current particles	Measure the wave properties (e.g., chorus, EMIC, hiss) concurrent with the 2-point measurements of the properties and time evolution of the unstable particle distribution functions to establish physical connections between the two satellites.	Measure 3 D and B waveforms and spectra as described in Goal 1. Measure simultaneously with measurements of source and seed population pitch angle distribution functions obtained at a TBD rate along with 2-D pitch angle distributions at a TBD rate. Goal: measure selected pitch angles and energy channels of plasma instrument (100 eV to 40 keV) at 1-100 Hz during burst to compare relevant waves.

AO Goal 6 Understand the effects of ring current and associated storm phenomena on radiation belt electrons and ions

Sub-Objective	Methodology	Measurements
<u>AO Objective 6c</u> . Determine how inner magnetospheric VLF waves associated with variations in the ring current and other plasma populations control radiation belt particle acceleration, transport, and loss	Method Use in situ measurements of ring current pitch-angle distribution and composition to compute growth rates of EMIC and VLF waves. Use observed values of EMIC/VLF wave power to develop and validate a model of EMIC/VLF waves. Integrate local loss/acceleration terms due to waves into kinetic radiation belt models.	Use measurements outlined in Goal 1. Provide these measurements during times when ring current ion and electron distribution functions are available. Provide all measurements during major major geomagnetic storms and other electron energization events and during substorm injection events. Provide measurements at all local times. Need to provide comparisons on time scales of ring current density and energy variations .

Goal 7 Understand how and why ring current phenomena vary during storms		
Sub-Objective	Methodology	Measurements
<p><u>AO Objective 7d.</u> Determine the location of overlap between the plasmasphere and the ring current (where EMIC waves, kinetic Alfvén waves, hybrid waves other possible plasma waves are generated, leading to radiation belt electron and ion scattering, loss, and acceleration).</p>	<p>Compare the location of the waves to the position the the overlap and use measurements of the properties of the waves in the .01 Hz to 100 Hz range to determine the wave mode structure, power, and amplitudes of the waves.</p>	<p><i>Measurements: Measure electric and magnetic fields of waves over frequency range 0 .1 Hz to -10 kHz in order to identify the mode structure and determine properties of waves Provide information on amplitudes of wave power and intense spikey structures, E/B ratios, phase velocity of wave, coherence, and k-vector magnitude and direction for mode identification.</i></p>

Goal 8. Modeling

Sub-Goal	Methodology	Measurement
AO Objective 8b) Develop global physics-based models suitable for describing the full range of electron and ion dynamics throughout the inner magnetosphere during all phases of the solar cycle.	Validate the specification and forecast performance of the global radiation belt model to determine output accuracy as a function of input data. Both case studies and the empirical model developed under Objective 8a will be used.	2-D Electric field from dc to TBD Hz; Accuracy: larger of 0.1 mV/m or 10%; Range: 0.1 mV/m to 300 mV/m from dc to 1kHz. Spin axis 5mV/m to 300 mV/m. [The full range of frequencies and amplitudes effecting particle dynamics.] DC electric field data could be a critical model driving parameter.
AO Objective 8c) Introduce data-assimilative capability to physics-based models appropriate for long-term reanalysis (climatology) and nowcasting (weather).	Develop algorithms to approximate (if necessary), condition and ingest current and historically available real-time data into the global radiation belt specification model developend under Objective 8b. Optimal data sets will be chosen based on validation results of Objective 8b.	See Objective 8
AO Objective 8d) Apply the data-assimilative models for reanalysis of the entire RBSP mission interval and, to the extent that long-term historical data is available, extend the reanalysis to an entire solar cycle.	(see AO goal 8 table)	See above for data

Time Duration of Intervals of Bursting Necessary for Understanding Wave Fields Responsible for Scattering/Acceleration of Energetic Particles

Phenomena at which waves could be found	Duration	# events per orbit	Total Burst durations	AO Sub-Goal
Substorm injection front turbulent wave field	600s	5	3000 s	1.1a, 1.1e, 2a, 4.1,4.2 5c,5e, 8b, 8c, 8d
Representative waves fields at radial distances of 2.0 -5.8 Re collected over ~0.5 Re intervals	60s	16	960	1.1a, 2a, 3c,3d 4.1,5e, 8b, 8c, 8d
Overlap boundary between ring current plasma and cold plasmasphere	400s	2	800s	2a, 4.1, 4.2, 6c,7d
Intense small scale structure associated with turbulent ULF/MHD wave fields	400s minutes distributed over 30 minutes	2	800s	1.1a, 2a,1.1e, 4.1, 4.2,4.5, 5c, 5e, 8b, 8c, 8d
Sub-structure of interplanetary shock induced magnetosonic waves	<u>~ 1 minutes</u>	<u>0.005</u>	<u>Negligible</u>	3c, 4.5, 8b, 8c, 8d
<u>Total Seconds of data</u>			<u>6040</u>	
<u>Total Requested, E.B.density</u>			<u>6168</u>	
<u>Total Requested Interferometric</u>			<u>320 s</u>	